*Medical images,*
*Automatic understanding,*
*Computer Aided Diagnostics*

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# NEW RESULTS OBTAINED USING THE MEDICAL IMAGES AUTOMATIC UNDERSTANDING TECHNOLOGIES

The paper presents newest results obtained during development of discovered by the authors new methodology of automatic understanding of medical images – used additionally or applied instead of its groove medical image processing, typical features analysis, and sometimes classical pattern recognition, object clustering and illnesses classification. This methodology is in fact knowledge based method of automatic reasoning, leading to very effective computer aided diagnosis process, necessary in many cases of medical practice. Using mathematical linguistic as a tool and applying cognitive resonance method we can solve many very difficult medical problems by means of semantic oriented medical images interpretation. Automatic understanding of images is also very useful tool for content oriented searching in multimedial databases (primary medical, but not only). Many times we need from big hospital databases (and also from library databases or Internet) some specific information, which can be described only in form of the example image ("show me data of all patient with similar type of cancer"). If content oriented searching must be used for text databases we can use many kind of known methods, e.g. ontologies. When compared data have multimedial form (for example medical images) the problem under consideration is much more difficult, because very often images containing the same semantic information (for example showing the same illnesses) are very different in form where images very similar in terms of the shapes of selected objects and its textures having quite different semantic (medical) meaning and interpretation. Only automatic semantic indexation of source databases by means of algorithms taking merit sense (semantic content) of the images combined with the same algorithms extracting merit sense from the image used as the key element of the question addressed to the database searching engine can give acceptable solution. The similar approach is now used also for design of special new kind of business decision support systems called UBMSS (Understanding Based Managing Support Systems), but this problem is out of scope of this paper.

## 1. INTRODUCTION

### 1.1. MEDICAL IMAGES AS A SOURCE OF DATA, WHICH MUST BE UNDERSTOOD

Medical images are nowadays very important and very popular source of information, used by medical doctors both for diagnosis and for planning of appropriate treatment. Many sources and may kinds of medical images available now gives a lot of visual data for investigated patient. For eyes of expert radiologist such images become deep and valuable information about morphology of organs under investigation and about health status of considered patient. But non every physician is expert radiologist and although well educated end experienced doctor sometimes can be tired or absent-minded. It means loss of information, which can be deducted from the medical image, but is

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neglected or omitted because of subjective (visual) methods used for it evaluation and interpretation.

One of the ways leading to improvement of analysis of medical images is using the computers as the advisors for the doctors. Computer off course can not replace the doctor, but can be very helpful in medical images interpretation, especially in case of doctors who are not expert for selected form of medical imaging. Computer vision method used traditionally for help of medical images interpretation performs three kind of operations.

First are systems for **image processing**. Good and properly performed processing can be very helpful, because eliminate majority of noises present in raw (source) image and can enhance the image quality especially in sense of presentation interesting features of the image (e.g. sharpening of the view of the organ under consideration while all other organs are removed from the image or included to the background).

Second is **image analysis.** Under this very voluminous term we can understand any calculation and measurement based on digital image, which gives parameters, useful for interpretation of the image. Very important and valuable is reduction of information volume connected with such step of image analysis. Typical medical image represents at last megabytes (sometimes gigabytes) of information volume and needs a lot of memory and computer power for storing and evaluation, while after properly performed analysis all necessary information about the important features of the objects on the image can be captured in the form of vector containing a few dozen of parameters.

Third step is **pattern recognition** named also **classification** of the image and connected directly with the main goal of whole medical image interpretation, e.g. medical diagnosis. Using very known methods of automatic classification, for example Bayesian rules, learning algorithms, k-mean or SVM methods and also off course neural networks model - we can try to prepare decision, which sometimes can automatically solve the problem under consideration.

All traditional steps of automatic processing and interpretation of medical images are not sufficient in the most difficult problems. In such problems we do need something more, over the processing, analysis and recognition, because for performing full interpretation of complex problem we must have the semantic interpretation of the image merit content. In fact the doctors activity during the image interpretation is not devoted to measurement some parameter or doing some classification. There are only the first steps on the long way leading to **understanding** of patients problem and the nature of the disease.

The understanding process is always based on the doctors knowledge – an this is the main difference between every method of the image processing, analysis and also recognition, which is ever **data-driven** procedure, and the task performed by the doctors mind, which is all the time **knowledge-based** reasoning.

Taking into account all the facts mentioned above we try to build mathematical models and also practical algorithms for **automatic understanding of medical images.** Proposed method is based on the linguistic description of the images, which must be prepared for every kind of images under consideration (e.g. coronarography or urography images) on the base of specially designed artificial *image content describing language*. After designing the structure of artificial language devoted to description the **merit sense** of the image under consideration, we must define special kind of graph-grammar, describing the rules of the proposed language and off course prepare automatic procedures for extracting necessary elements (so called graphical primitives and graphical relations) playing role “nouns” and “verbs” of defined grammar.

The structure of designed grammar must include as much as it is available elements of doctors knowledge both about the illnesses under consideration and about the structures and its morphological deformations which can be visible on the images under consideration. It is difficult and in fact it is the bottleneck of the presented methodology – but in numerous previous papers we prove, that this is possible and it works.

When we have the proper (knowledge based!) grammar and we can convert every particular medical image (of selected type) to the merit based linguistic description – we can perform automatic parsing. The parsing process used in our methodology to automatic understanding of the images is very similar to the process of automatic translation the text of the computer program form the selected algorithmic language (e.g. C++) to binary code which can be performed directly by microprocessor. As is commonly known, in the case of automatic translation of the programs as the input for the translation process we have text of the program written by the programmer (not applicable to the microprocessor structures) and as the output we can obtain the same program transformed to the meaningful form of codes accepted by the hardware and ready for execution. In our case we have on the input of parsing process the description of the analyzed image expressed in the form of sentence in special language, but this description is until now controlled only by the form of image and visualized medical structures. The parsing process ought transform this description of the **form** of the image to the description of the **sense** of the image. If we can do it, we told, that we obtained the merit content of the image or that we **understood** the image.

During the parsing process two streams of information are combined and in some sense collided. First stream starts from the analyzed image and brings all details of the morphology of observed organs. Second stream starts from the doctors knowledge represented in from of designed graph-grammar and developed parser. This second stream of information brings some demands to the forms which **can** be observed on the image when some of merit interpretations of the image become true. The confrontation between demands taken form the knowledge base and real parameters and features extracted from the input image is very similar to the interaction between two waves (for example during light interference). Some of facts derived from the knowledge gains some features disclosed on input image. Other features of the image can disclose conflict with some expectations based on the knowledge, what leads to the changing of working hypothesis about the understanding of the image merit sense. Because of this characteristics all iteratively preformed process, connected with parsing of linguistic description of the image, based on the knowledge incorporated to the parser structure, we called cognitive resonance.

During the presentation details of the above mentioned method will be presented and some successful applications will be discussed.

### 1.2. SHORT HISTORY OF DISCOVERY AND DEVELOPMENT OF AUTOMATIC UNDERSTANDING IDEA

Five years ago we introduced the very new paradigm: automatic understanding of the medical images [1] instead of its processing, analysis and also automatic recognition. In some sequencing papers we describe the new methodology more and more detail [2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20]. Moreover we try to extend methodology of automatic understanding of the images toward to automatic understanding of the signals (in general) [21]. Very fast this paradigm becomes popular and was quoted also in the books of other authors [22]. At the last two years ago the approach based on automatic understanding of the images was also described in details in the special monographic book [23] and in chapters of another books [24].

Full description or the idea of automatic understanding of the medical images is too comprehensive for its full presentation in such short paper. Nevertheless some general outlook of the principles of this method is necessary for further discussion, therefore it will be done in next chapter.

## 2. GENERAL IDEA OF AUTOMATIC UNDERSTANDING

Modern methods of computer vision, a field of informatics connected with artificial intelligence, allows thorough **analysis** of images bringing out their parameters and numerically defining the selected features of the registered objects. We can also recognize the defined types of objects. But all these conventional techniques of computerized handling of images (collected in the form of a compact diagram in fig. 1) do not move us nearer to understanding the meaning of what is revealed in the form of the image, as they refer to its form only.

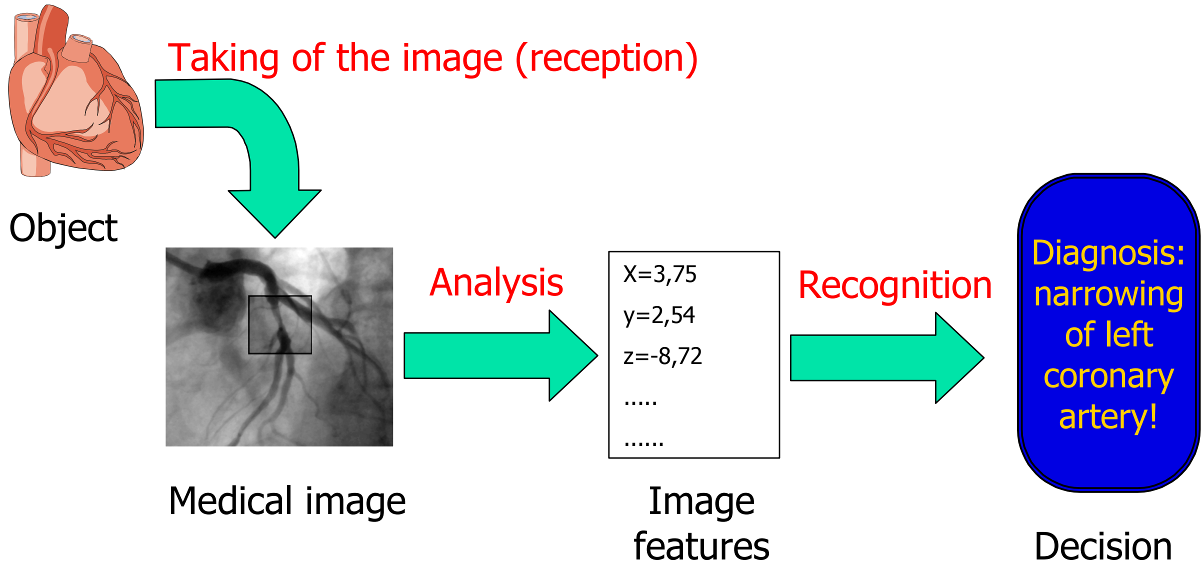


Fig.1 Traditional methods of medical images interpretation

Consequently, we do not know what it means that certain features and parameters of objects measured in the image have certain values calculated by the computer, because we are not able to link any meritorious meanings to these objects, parameters, or values. Of course, analysis of the image and parameters defined in result of such analysis are often very useful in case of simple assessments. We can compare, for instance, values referring to a given patient with the values recognized as ”physiological standard”. Image analysis gives us also very helpful numerical values of the features of selected objects (i.e. shapes and dimensions of organs or parts of organs). This is very important and useful.

In order to systemize further consideration we will try to indicate what is characteristic for the components of *computer vision technique*:

- **Image processing** allows to answer the question: how to make the content of an image better visible?
- **Image analysis** allows to answer the question: what features has a thing we see at the image?
- **Image recognition** allows to answer the question: how to classify things visible at the image?

**Automatic image understanding** allows to answer the question: what appears from what we see? What is the meaning of the fact that visible objects have certain features? What consequences arise from the fact that objects may be assigned to certain selected classes?

The following set of features of image understanding is consistent with the concept:

- Natural way of thinking of a human expert is imitated as closely as possible;
- Creation of a linguistic description of the meritorious content of the image allows its semantic representation without aprioristic definition of a number of the recognized classes;
- The created linguistic description is of structural character and allows us to analyze the meaning of the image, as detailed as needed for classification or indexation purposes.

Further, we may state that **image recognition** always employs a certain number of preset patterns, and processing of image information aims at bringing such features out of the image, which will allow to assign the image to one of preset classes. Such model of processing assumes one-way flow of signals (fig. 1). Contrary to this diagram, in case of image *understanding*, information flows in two directions, because the flow of empiric data from registering and image analyzing subsystem interferes with the flow of *expectations* (fig. 2). The expectations are a kind of postulates defining properties of the examined image assuming that the meritorious image content meets one of the possible variants of its **semantic** interpretation. At the same time it is assumed that an image understanding system has a set of *expectations* generators connected with various possible ways of meritorious interpretation of the image content [1], [2], [3].

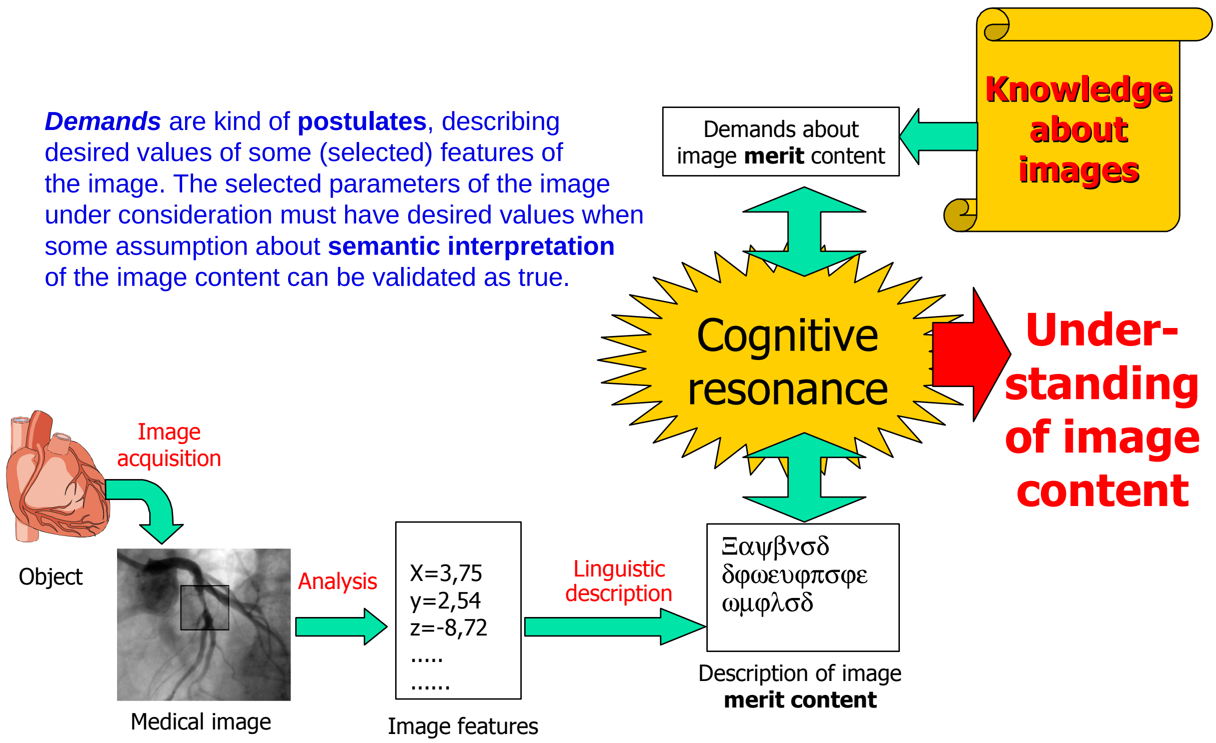


Fig. 2. Two-way information flow during the test of image understanding

## 3. IMPLEMENTATION OF THE IDEA AND EXAMPLES OF SOME PROBLEMS SOLVED BY MEANS OF AUTOMATIC UNDERSTANDING CONCEPT

In the papers and articles quoted in 2 chapter we do use concept of automatic understanding of the medical images for solving of some medical problems: understanding of the pancreas illnesses (e.g. differentiation between pancreatic cancer and permanent inflammation [1, 2, 3, 4, 5]), understanding of the heart coronary arteries condition, understanding of problems with renal pelvis and ureters and so one. The typical problem under consideration in such earliest works is shown on fig. 3.

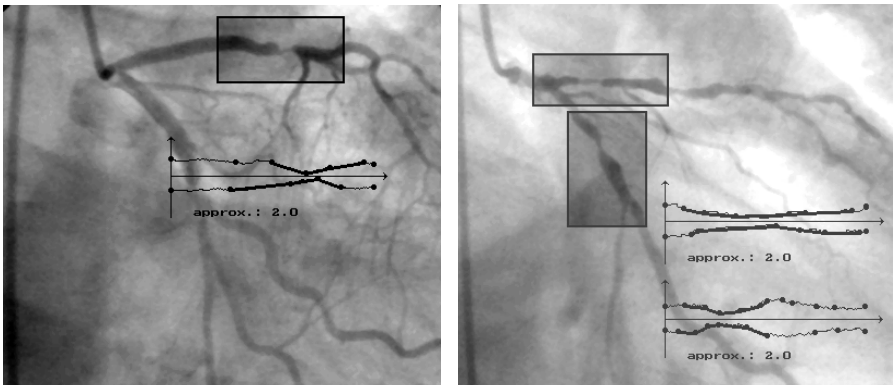


Fig. 3. Coronary arteries stenoses as a typical problem for application of medical understanding methods from previous works

For such types of images we developed and proved complete and efficient methodology of transforming input medical image (throw many preprocessing and analysis steps – see Fig. 4) into its linguistic description (using one of developed graph grammars, defining special type image description languages), which can be next transformed into semantic interpretation of the image merit content using parsing process.

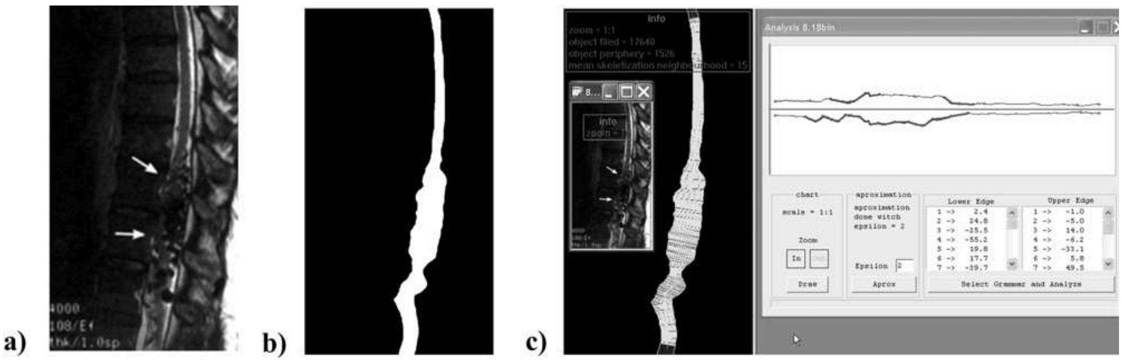


Fig. 4. Example of preprocessing of medical image performed before starting of autmatic undestanding procedures

In our formalization the way to automatic understanding of the image is very similar to translation of the computer program algorithmic ideas, written first in abstractive high level algorithmic language like C++, to processor applicable binary codes. Most important elements of this way can be seen on fig. 5, presenting way from medical image (pancreatic duct ERCP visualization), which is analogy to the program written by the human programmer in algorithmic language, throw many steps of parsing – to semantic description containing result of automatic understanding of the merit content of the image, which is analogy to the final binary code.

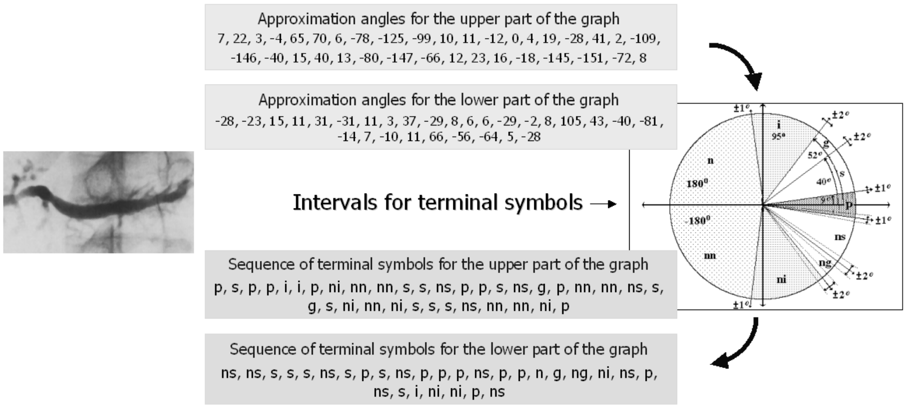


Fig. 5. Shape representation in the form of a sequence of symbols representing individual contour fragments, which is key point of automatic understanding of the image content

The methods of automatic semantic evaluation of selected types medical imaginations was developed and enhanced long time, using many special constructed by authors software tools (see Fig. 6), which can accept medical image as an input and produce semantic description of the medical problem under consideration as an output.

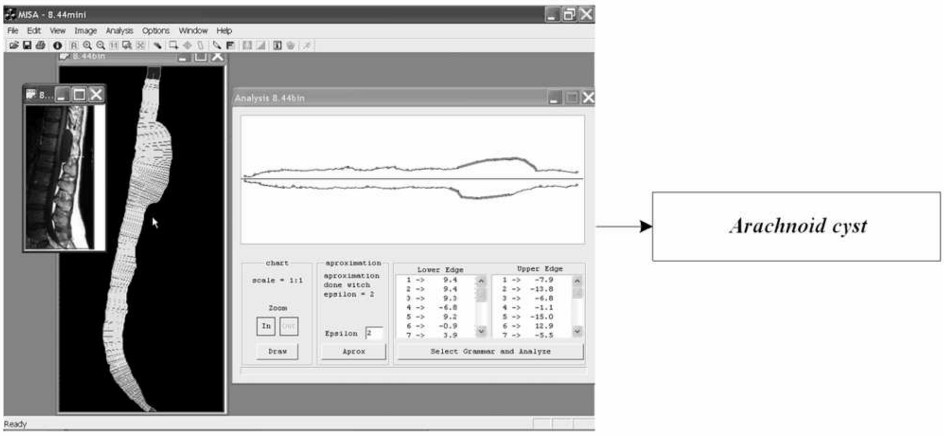


Fig. 6. Example of the software dedicated to automatic understanding of the images at work. On this example diagnostic description of pathological lesions in spinal cord is presented with marked automatically recognized cyst

Many other examples of the successful applications of presented methodology (which details omitted here because of the limited space) can be found in articles quoted in bibliography below.

## 4. NEW PROBLEMS SOLVED BY MEANS OF AUTOMATIC UNDERSTANDING CONCEPT

All the problems mentioned above was very important from medical point of view and needs understanding of the actual state of the ill organ as well as mental reconstruction of the pathological processes, leading to the situation, which was registered on the images under consideration. But from the computer point of view the problems solved was quiet simple and therefore automatic reasoning can be also rather simple.

Fig. 7. Examples of new cases of multi-object medical images, which needs application of enhanced methods of automatic understanding: a case of avascular necrosis of lunate (Kienbock's disease - left) and image showing calcification (arrow) in the region triangular of the wrist (right).

Starting from the assumption, that methods, used for deriving of conclusions in simple cases, can be also applied to the much more complex problems, authors try elaborate new algorithms for new problem, which are based automatic understanding of the images, but the new problems, solved using the same approach are much more complicated.

First we move to the images of more complicated medical images, on which we must consider not one, but many objects. Typical example of such object can be images of wrist bones, shown on fig. 7. The problems, which must be solved now are much more difficult, because we must understand merit content of the shape of every visualized object, and additionally we must understood all conclusions taking from mutual relations of many objects, forming together the complex biomechanical system.

Medical problems like shown on fig. 7 was discussed in newest papers of authors (see [25, 26, 27]), where new type of image description language was proposed and new type of graph grammar as a mathematical tool for its formalization was discussed. Not going to all details, which are complicated and therefore its full description can be found in above quoted articles we would like to stress, that the key tool, allowing approach of automatic understanding methodology to such kind of medical images is special kind of graph grammars. For the analysis of wrist radiogrammes an expansive graph grammar was defined.

$$G_{exp}=(N, \Sigma, \Gamma, P, S)$$

Non-terminal set of peak labels

$N= \{STS, U S, L, T, P, TM, TZ, C, H, M1, M2, M3, M4, M5\}$.

Terminal set of peak labels

$\Sigma=\{r, u s, l, t, p, tm, tz, c, h, m1, m2, m3, m4, m5\}$

Γ - edge label set

$\{s<p<q<r<s<t<u<w<x<y<z\}$

Start symbol

$S=STS$

P – is a finite production set presented on Fig. 8.

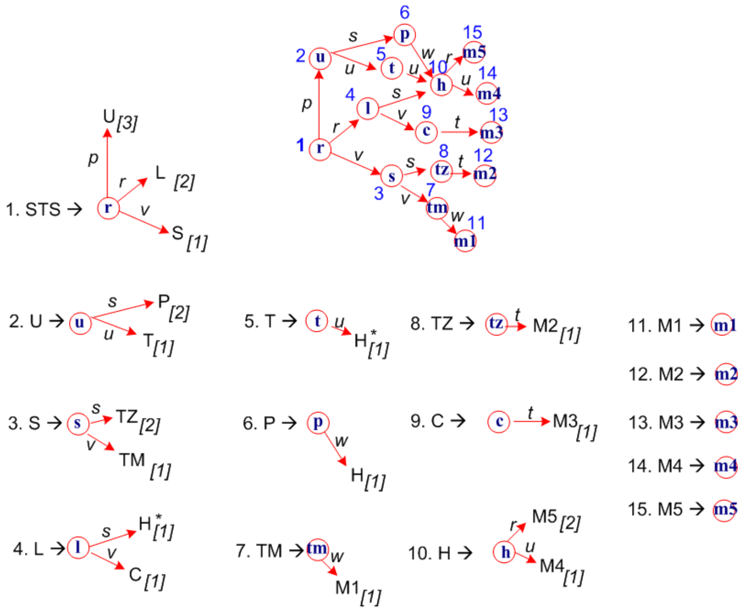


Fig. 8. Production/graph set introducing a representation of the correct build and the number of bones in the wrist

Possibilities to describe image cases showing additional wrist bones can be obtained by enriching the above-presented set of rules introducing the formulas of the analysed grammar by productions defined on Fig. 9. Set of non-terminal labels *N* will then contain also an additional peak label, 'Acc Bone' standing for the reasoning tree for the new object/bone appearing on the image (in the first series) and located in accordance with the labelled directions.

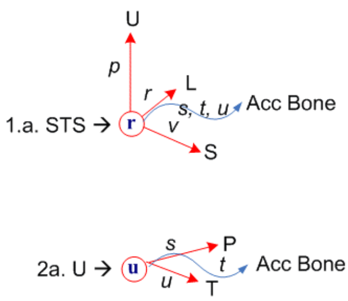


Fig. 9. Production set describing additional bones in wrist radiogrammes. For simplification, in these productions peak and graph ordinals as well graph location, operators were omitted.

Image showing other pathology forms in wrist image: synostoses or bone defects can be recognised with the use of alternative rules specified on Fig. 10. In this case an additional 'Fuss' peak appears and stands for the introduction of an additional bone, originating from the merger of two neighbouring ones.

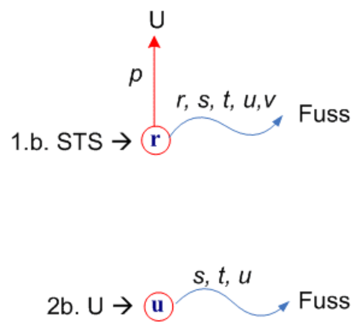


Fig. 10. Production set describing bone defects caused by bone joints or by bone dislocation

Another problem actually analyzed and solved by means of automatic understanding methods is problem of application of developed methods for 3D medical imaging. Because of lack of space we can not going into details of such problem and its solving proposed by us and by other authors, but on the figures 11 and 12 we show, how the elements of special kind graph grammars are adopted to the linguistic description and after this semantic analysis of selected 3D medical images.

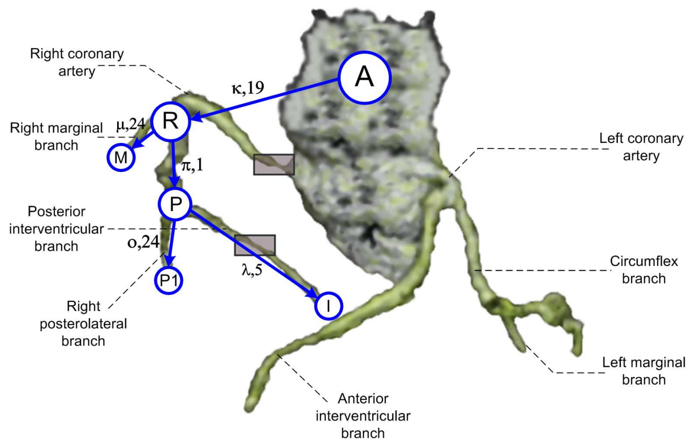


Fig. 11. Using of graph grammar elements for description of 3D medical images

The full methodology of the lingusitic description and semantic analysis of 3D medical images is described in newest paper [28] and selected results of this newest works can be found in papers [29, 30]. These papers presents the new opportunity for making semantic descriptions of medical structures with the use of AI graph-based linguistic formalisms. Discussed in detail are the manners of applying methods of computational intelligence to the development of a syntactic semantic description of spatial visualisations of the heart's coronary vessels. The methodology can be used for attaining other goals related performance of computer-assisted semantic interpretation of selected elements and/or the entire 3D structure of the coronary vascular tree. The obtained semantic information makes it possible to make a description of the structure focused on the semantics of various morphological forms of the visualised vessels from the point of view of the operation of coronary circulation and the blood supply of the heart muscle. Thanks to these, the analysis conducted allows fast and – to a great degree – automated interpretation of the semantics of various morphological changes in the coronary vascular tree, and especially makes it possible to detect the stenosis in the lumen of the vessels that can cause critical decrease of blood supply to extensive or important regions of the heart muscle. This is achieved through the use of graph-based image formalisms based on IE graphs (indexed edge-unambiguous) generating grammars that allow discovering and automatic semantic interpretation of irregularities visualised on the images obtained during diagnostic examinations of the heart muscle from helical CT scans.

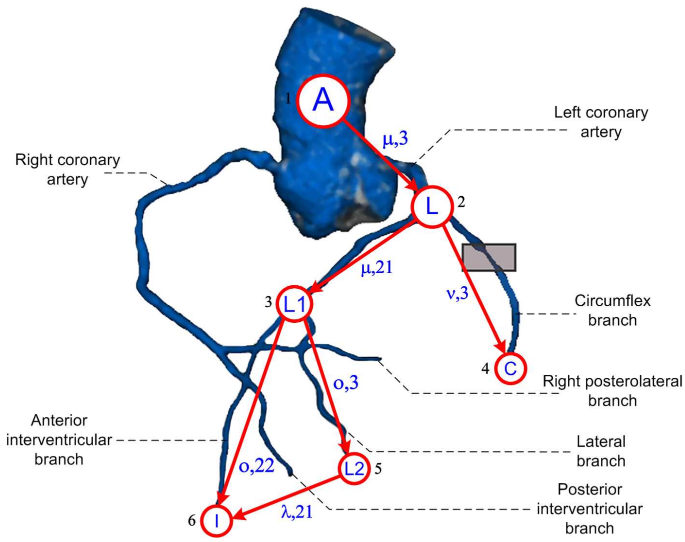


Fig. 12. Semantic analysis of 3D medical image by means of graph grammar elements for its automatic undestsanding

## 5. CONCLUSIONS

In the paper we remark about some old and newest results, obtained by means of discovered and developed by us new methodology called medical images understanding technology. Described methods can be found as very powerful and very interesting new tool for processing of medic data, particularly many kind of 2D and 3D medical imaging, but its usefulness is not limited to this area. In latest papers [31, 32] we show usefulness of this methodology also for design of special new kind of business decision support systems called UBMSS (Understanding Based Managing Support Systems), but this problem is out of scope of this paper.

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